A METHODOLOGY TO PREDICT CORROSION EFFECTS ON THE RELIABILITY OF ELECTRICAL DEVICES

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Atmospheric corrosion is one of the leading age-related degradation modes observed in high-consequence electrical components. An effort is now underway at Sandia to develop a comprehensive science-to-engineering tool-set that can be used to assess the effects of corrosion on the performance and reliability of these types of components. For this tool-set to be truly predictive, it must be based on a mechanistic understanding of the corrosion degradation phenomena. Computational capability requires the use of a deterministic, continuum-level mathematical model. Uncertainty analysis must be included to address the stochastic nature of corrosion and environmental conditions. Finally, to determine reliability, the output must interface with age-aware electrical models of component/system performance.

This presentation will describe our approach using corrosion of a gold-plated electrical contact as an example. We have also applied this process to corrosion of Al bondpads in microelectronic devices and sulfidation of a diode. The important aspects that are incorporated in this approach include:

- **Corrosion issues**: An analysis of historical occurrences led to the definition of two general types of corrosion that affect electrical function: (I) product layer growth and (II) voiding. Specifically, corrosion of copper, nichrome and aluminum metallization features are of primary interest to us. For this example, the concern is creep corrosion occurring on Au-plated Cu connectors. The corrosion reaction is sulfidation of the Cu through pores in the Au (Figure 1), with corrosion products spreading across the Au surface. If this occurs beneath a contact point, an increase in contact resistance is observed.
- **Physical understanding:** Fundamental, quantum mechanical and ab-initio calculations combined with parallel micro-lab experimentation are being used to identify pertinent mechanistic understanding. In this example, the Cu sulfidation process is being characterized.
- **Continuum model:** The core of this tool-set must be a deterministic continuum-level model. The physical understanding leads to a set of simplified governing equations that describe the degradation process. Other important aspects of the core model include the ability to address moving boundary layers and the multiple dimensions and configurations associated with real devices. For corrosion of electrical contacts, important processes include gas / solid-phase mass transport and corrosion product morphology / electrical properties. Kinetic parameters and physical properties are either experimentally measured or estimated through fundamental calculations – diffusion coefficients (gas and solid) and surface reactions rate constants. Device-specific information includes contact configuration, Au thickness, and Au pore size and distribution.
- **Environmental definition:** A critical input is an accurate definition of the device environment. For a population of devices, the environment will be neither constant nor uniform. Thus, the environment must be treated as a distribution of values that will be time-dependant.
- **Uncertainty-based simulation:** Because many aspects of the ultimate assessment are not deterministic (e.g., environment, physical properties, rate constants), a capability to address uncertainty is essential. Also of note, computational efficiency requires the use of advanced uncertainty analysis techniques. The simulation itself will provide a time-based series of distributions of the electrical property that corrosion affects. In the case of electrical contacts, creep corrosion (sulfidation) of the Cu results in increased contact resistance. Thus, the output from the simulation is a distribution of resistance values associated with the presence of copper sulfide at the connector interface. Figure 2 shows output from a simple finite element simulation assuming that diffusion in the solid corrosion product is rate limiting.
- **Reliability assessment:** Direct integration with electrical-system models is required because device failure can only be defined within the context of a fully functional component. Therefore, the distribution of property changes output from the simulation is input into an age-aware electrical system model to determine the effect of corrosion on component or system-level reliability.

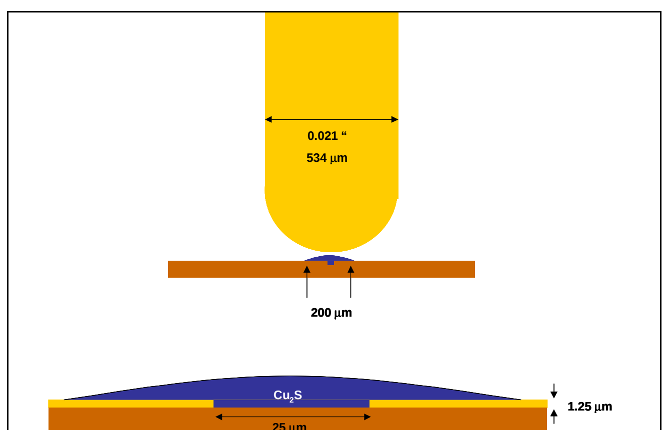

Figure 1. Schematic of simulated electrical contact showing the presence of creep corrosion (sulfidation) on one contact.

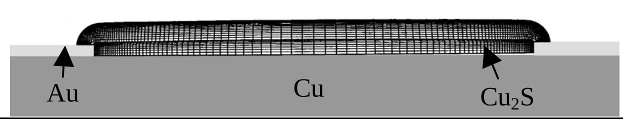

Figure 2. Sulfide layer growing through a pore in the Au plating. The sulfide was generated assuming Cu diffusion through the product layer is rate limiting.

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